PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B23K 26/00

A1

(11) International Publication Number: WO 00/69594

(43) International Publication Date: 23 November 2000 (23.11.00)

(21) International Application Number: PCT/US99/11044

(22) International Filing Date: 18 May 1999 (18.05.99)

(71) Applicant: UNITED STATES ENRICHMENT CORPORATION [US/US]; Two Democracy Center, 4th floor, 6903 Rockledge Drive, Bethesda, MD 20817 (US).

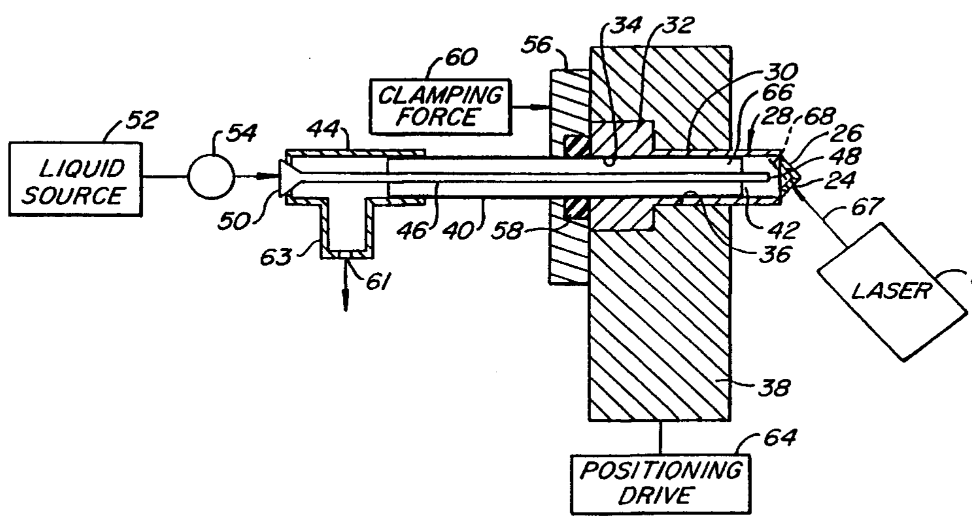
(72) Inventors: WARNER, Bruce, E.; 4204 Casterson Court, Pleasanton, CA 94566 (US). ROCKHOLD, Charles, T.; 2199 Lagrange Court, Livermore, CA 94550 (US).

(74) Agents: LEMOND, Kevin, T. et al.; Townsend and Townsend and Crew LLP, 8th floor, Two Embarcadero Center, San Francisco, CA 94111-3834 (US).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: METHOD AND APPARATUS FOR LASER MACHINING WORKPIECES WITH LIQUID BACKING



(57) Abstract

Small precision holes (24) are formed in a front wall (26) of a workpiece with a pulsed laser beam. The workpiece includes a back wall which is spaced from the front wall (26) and forms a passageway therewith. A laser beam attenuating fluid, such as a laser beam energy absorbing or scattering liquid, is circulated through the passageway and is selected so that the liquid absorbs sufficient laser beam energy to prevent any portion of the laser beam which may strike the back wall (or which may be scattered onto the front wall (26)) from damaging the walls by burning depressions or holes therein. The liquid is circulated through the passageway at a sufficient rate to prevent it from being overheated or evaporated by the laser beam and, following conditioning, the liquid can be recirculated into the passageway. The laser beam hole-forming method can be used for machining small-diameter precision orifices in internal combustion engine fuel injectors (28).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

METHOD AND APPARATUS FOR LASER MACHINING WORKPIECES WITH LIQUID BACKING

The United States Government has rights in this invention pursuant to Contract No. W-7405-ENG-48 between the U.S. Department of Energy and the University of California.

BACKGROUND OF THE INVENTION

This invention relates to the precision machining of workpieces with radiation beams, such as laser beams, and protecting those portions of the workpiece which would otherwise be struck by the laser beam after it has made the cut against damage by the beam.

Many workpieces, such as fuel injectors for internal combustion engines, for example, require the formation of very small-diameter precision holes through a variety of materials, from plastics to hard-to-machine materials such as metal or ceramics, for example. While holes are normally drilled, drilling becomes exceedingly difficult as the diameter of the holes becomes smaller. Fuel injectors for internal combustion engines, for example, require the formation of holes having diameters in the range of between 150-200 microns ("μ") with a tolerance of as little as $\pm 1\mu$. Such small-diameter holes, for example, are ideally suited for laser machining; that is, directing a precisely controlled laser beam having the required energy against the workpiece to burn through it and thereby form the hole.

When there is a wall ("back wall") spaced from the wall ("front wall") through which the hole is to be formed, the laser can impinge on the back wall after it has cut the hole in the front wall and damage it, e.g. burn a depression or even a hole into the back wall. To prevent this, it has been common practice to place solid backing between the front and back walls. Solid backing used in the past includes materials, such as metal or plastic, which are placed in the space between the walls to absorb the laser radiation

penetrating through the front wall. This has several shortcomings.

First, it is difficult to place solid backing in small parts or in parts which provide limited access to the surface that is to be protected. Second, solid backing materials can melt and/or become vaporized when subjected to the laser beam, causing a dispersion of the backing material onto the workpiece. This can cause problems when adhering backing material must be removed from the workpiece before it can be used. Third, the backing material is often more readily burned through by the laser beam than the material that it is to protect and, as a result, the backing material frequently offers only limited protection.

Ideally, the backing material should be able to withstand, without adverse effects for the workpiece, full illumination by the laser beam while protecting the back wall against any damage from the beam. Such backing materials should further be inexpensive, easily placed in the proper position, and their properties should be adjustable for different workpiece geometries and laser beam energies.

SUMMARY OF THE INVENTION

The present invention overcomes the shortcoming encountered with prior art backing methods to prevent radiation, e.g. laser beams, from damaging the workpiece by reducing the energy density or concentration of the beam so that it either does not reach the opposing wall at all, or reaches it with a sufficiently low energy density that it cannot cause damage. This is accomplished by placing a laser beam absorbing or scattering fluid, typically a liquid, in the passage between the front and back walls. Laser (or other radiation) beam absorbing liquids may include, but are not limited to, liquids, including water as well as other liquids, mixed with an energy absorbing dye. Sufficient dye is mixed into the liquid so that the laser beam is attenuated to the desired degree over the length of its beam which extends through the liquid.

Alternatively and/or additionally a laser beam light scattering material, such as small particles, may be added to the liquid in the needed concentration so that laser light breaking through the front wall of the workpiece is sufficiently scattered in the passageway between the front and back walls that no part of the walls receives laser light having an energy density which might cause damage.

The precise manner in which the passageway between the front and back walls is filled with the laser light absorbing fluid depends to a significant extent on the size and physical dimensions of the workpiece in question, including the shape and accessibility of the passageway. Further, the technique employed in any given instance will depend on the material of which the workpiece is constructed as well as the laser energy that is being employed. Generally speaking, however, the fluid may be a liquid, a viscous and/or gel-like substance, which may be flowed, injected or otherwise transported into the passageway and, under appropriate conditions, the fluid might even be a gas. Further, the fluid may remain stationary in the passage, e.g. it may be filled into the passage and remain there until after the laser cutting is over or, more typically, the fluid will be circulated through the passage. For purposes of this application, the fluid (whether a liquid, a gas, a gel, etc.) in the passage between the walls will at times be referred to as "liquid backing."

A presently preferred embodiment of the invention uses the liquid backing for machining precision orifices, such as transpiration cooling channels in turbine blades, or fuel discharge orifices in fuel injectors of internal combustion engines. The latter typically have a blind hole with an end wall through which one or more orifices of diameters in the range of between 100-500μ must be formed. The laser beam attenuating liquid may be water mixed with a dye (for example, red dye) and it is circulated through the passage with two concentric conduits. The inner conduit is a needle which has an open end located proximate the end wall of the injector and it serves as the inlet conduit for the liquid. The outer

conduit surrounds the needle, is sealed to the open end of the passage of the injector, serves as an outlet, and transports the liquid away from the passage.

To prevent an overheating and possible evaporation of the liquid, which could expose and damage the back wall, it is circulated through the injector passage at a sufficient rate so that it is not overheated by the laser beam. For continuously operating lasers, this can be done by controlling the flow rate so that there is an energy balance between the power or heat absorbed by the liquid and the power or heat removed by flowing the liquid out of the passage. When pulsed lasers are used, overheating can be prevented by flowing the liquid through the passage at a sufficient rate so that any given liquid volume subjected to laser light during one laser pulse has been replaced with a fresh volume of liquid by the time the next succeeding laser pulse is generated.

Further, to prevent the liquid from emerging from the orifices as they are formed by the laser, the present invention operates the liquid circulating system so that the pressure at the outlet conduit is at or only minimally above or below atmospheric pressure (on the exterior of the injector) to prevent the liquid from emerging from the orifice, or have air enter through the orifice(s) and become entrained in the liquid if its pressure is too much below atmospheric pressure.

The present invention additionally provides a system so that workpieces, such as the earlier discussed fuel injectors, can be moved relative to the laser beam for forming several, spaced-apart orifices in the injector.

Thus, the liquid backing provided by the present invention effectively prevents laser beams from damaging opposing walls after they have burned through the front wall without adversely affecting the workpiece, while requiring minimal labor. It therefore enhances the efficiency of laser machining and significantly reduces the costs thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 schematically illustrates a first aspect of the present invention;

Fig. 2 schematically illustrates a second aspect of the present invention; and

Fig. 3 is a schematic, side elevational view, partially in section, which illustrates the method and apparatus of the present invention in more detail.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 1, in a first embodiment of the present invention a laser beam 2 is used to machine or, more precisely, to burn a hole 4 through a front wall 6 of a workpiece 8. A back wall 10 is spaced apart from the front wall, overlies the hole in the latter, and with the front wall defines a passageway 12 inside the workpiece which is accessible through an access opening 14 of the workpiece. A laser beam absorbing liquid 16, such as water mixed with a laser beam absorbing dye, fills the passageway and flows from the access opening 14 to a discharge opening 18 of the workpiece.

To cut hole 4 in front wall 6, the laser beam is aimed against the latter to burn a precision hole into the wall. When the laser beam breaks through the front wall after hole 4 has been opened, it impinges on liquid 16 in the passageway 12. As the laser beam traverses the liquid the radiation absorbing dye thereof attenuates the laser beam and reduces its energy density so that the front end of the beam either does not reach back wall 10 at all or its energy density will have been reduced sufficiently so that it does not damage the front wall; that is, so that it neither forms depressions therein or a hole therethrough.

Since the passageway is typically of a given, unchangeable size, the laser beam attenuating liquid 16 must be capable of absorbing at least enough laser energy over the length of the path of the beam through the liquid to prevent the beam from damaging the back wall until the laser beam can be repositioned or turned off. Thus, the type of liquid used

in passageway 12, the concentration of laser energy absorbing material in the liquid, or the absorbing capacity of the liquid itself must be selected on the basis of the energy density of the laser beam and the length of its travel path through the liquid before it strikes the back wall. For example, the laser radiation absorbing capacity of the liquid can be increased by increasing the concentration of the earlier mentioned dye in the water. Those skilled in the art can readily make the necessary adjustments to adapt the laser beam attenuating quality of the liquid in the passage for each new application.

Since liquid 16 absorbs energy from the laser beam, it becomes heated by it. To prevent an over-heating of the liquid by either a continuously operating or a pulsed laser beam, which might lead to its evaporation or a reduction of its energy absorbing capacity, the liquid is circulated through the passage at a sufficient rate as was discussed above. This can be done, for example, by appropriately pumping the liquid at a controlled rate.

Referring to Fig. 2, a hole 4 is formed in front wall 6 with a laser beam 2 in the same workpiece 8 as is shown in Fig. 1. The liquid 20 in passageway 12, however, is not a laser beam absorbing but a laser beam scattering liquid. For example, small particles 22 of the appropriate size may be entrained in the liquid in sufficient concentration so that the laser beam entering the passage through the hole in the front wall becomes scattered and thereby diffused in many or all directions. As a result, laser light eventually striking one of the walls 6, 10 will have a sufficiently low energy density that the walls will not be damaged.

Scattering liquid 20 may at times absorb relatively less heat from the laser light. Hence, there is a lesser danger of over-heating and the scattering liquid can flow at a lesser rate through passageway 12 or, under appropriate circumstances, blind holes and the like (not shown in Fig. 2) can be cut without having to circulate the liquid into and out of the hole. Further, since in such instances the liquid need not be flowable, substances such as highly viscous material,

gels or the like can be placed into the passageway by flowing or injecting them, preferably after the scattering particles 22 have been entrained.

Referring now to Fig. 3, in a specific embodiment of the invention it is used to burn or machine small-diameter orifice holes 24 in an end wall 26 of a fuel injector 28 for an internal combustion engine. The fuel injector has a tubular body 30, a flange 32 at the end of the injector opposite from end wall 26, and an access opening 34.

Before the orifices are formed, the injector is placed into an appropriately shaped mounting hole 36 in a positioning jig 38.

The end wall 26 of the injector projects past and is accessible from the exterior of the jig. A flow tube 40 is inserted into an interior bore 42 of the injector and has a free end coupled to a T-shaped inlet fitting 44.

An elongated inlet conduit, preferably in the form of a hollow needle 46, is inserted through an opening in the end of fitting 44 and extends deep into the blind bore 42 of the injector so that an open end 48 of the needle is proximate but spaced from injector end wall 26. As schematically illustrated, the other end 50 of the needle is fluidly coupled to a source 52 of laser beam attenuating liquid via a pressure regulator, valve or the like 54 so that the liquid can be flowed from the source through the regulator and the needle into the bore of the injector.

A locator plate 56 is slipped over flow tube 40 and includes a recess on the side of the plate facing jig 38 which receives a compression seal ring 58. The locator plate is pressed against the jig with a sufficient clamping force 60 to compress seal ring 58 so that a seal is established which prevents liquid from leaking from between the exterior of flow tube 40 and injector bore 48. Clamping force 60 can be generated in any desirable manner such as with a manually activated clamp, a mechanical, electrical, magnetic power drive, and the like, all of which are well known to those skilled in the art and, therefore, are not further described herein.

In use, and following the insertion of the injector into the jig, the installation of the flow tube 40 and needle 46, and the compression of seal ring 58, laser beam attenuating liquid is circulated through the laser bore by flowing it from the source 52 through the needle and out its open end. The liquid flows over the inner surface of end wall 26 and then gradually migrates out of the injector bore in the annular space defined by the inside of flow tube 40 and the exterior or needle 46. Seal ring 58 prevents any leakage of liquid and the liquid is eventually withdrawn through a hole 61 in a branch 63 of T-fitting 44.

In the preferred embodiment of the invention, withdrawn liquid is reconditioned by removing impurities from it, cooling it as needed, replenishing liquid and/or laser light attenuating materials therein (such as dye), and then returning it to the liquid source for recirculation through the injector mounted in the jig.

After the liquid flow has been initiated, a laser 62 is activated and jig 38 is repositioned with a positioning drive 64 so that a laser beam 67 strikes injector end wall 26 at the location where orifice 24 is to be formed. The laser beam striking the end wall melts the material of the wall, may partially or wholly evaporate it, and after the orifice is formed the laser beam enters the laser beam attenuating liquid 66 in the base of the injector. Dotted line 68 shows the path of the laser beam through the liquid and where the beam would strike the tubular body 30 of the injector, which, in the terminology of this application, forms a back wall. As the laser beam traverses the liquid in the bore of the injector, its energy density decreases, by absorption and/or scattering, so that it does not damage the body of the injector.

After the orifice has been formed, a positioning drive 64 can be activated to reposition the injector relative to the laser so that the laser beam strikes the end wall at a location where another orifice (not shown in the drawings) is to be formed. This can be repeated any number of times until all orifices have been formed in the end wall.

After the first orifice 24 has been formed in the injector end wall, liquid 66 might leak through it from the injector bore 42 to the exterior of the injector. To prevent this, the pressure of the liquid in the bore is carefully controlled so that it is as close as possible to the ambient pressure, for example with pressure regulator 54. At such a pressure there will be no or only minimal leakage through the orifice. Further, by preventing the liquid pressure from dropping significantly below the ambient pressure, the inflow of ambient air through orifice 24 into the liquid is prevented. The formation of air inclusions in the liquid, which might adversely affect the liquid's ability to attenuate the laser beam, or which might adversely affect the circulation and conditioning of the liquid following its exposure to the laser beam, are thereby prevented.

Further, the liquid source is calibrated so that the liquid flows at a sufficient rate through the portion of injector bore 42 illuminated by laser beam 66 so that a new volume of liquid is traversed by each successive laser beam pulse as was described in more detail above.

WHAT IS CLAIMED IS:

1. A method of machining a workpiece with radiation, the workpiece having a front wall through which an opening is to be machined and a back wall spaced from the front wall, overlying the opening and with the front wall defining a fluid passage between the walls, the method comprising the steps of directing radiation against an area of the front wall and with the radiation forming the opening through the front wall, placing a fluid in the passage which attenuates the radiation sufficiently so that the radiation cannot remove material from the back wall, terminating the directing step after the opening in the front wall has been made, and thereafter removing the fluid from the passage, whereby damage to the back wall from the radiation is prevented.

2. A method according to claim 1 wherein the step of placing the fluid in the passage comprises the step of placing a liquid in the passage.

3. A method according to claim 2 wherein the step of placing the liquid comprises flowing a liquid stream through the passage during the step of directing the radiation against the front wall.

4. A method according to claim 3 wherein the step of flowing comprises the steps of flowing the liquid into the passage at a first pressure, withdrawing the liquid from the passage at a second pressure, and maintaining the second pressure at a vacuum relative to pressure prevailing on a side of the front wall opposite from the passage.

5. A method according to claim 3 wherein the step of directing radiation comprises generating a laser beam, and directing the laser beam against the front wall to form the opening.

6. A method according to claim 5 wherein the step of generating the laser beam includes the step of pulsing the laser beam at a predetermined frequency, and wherein the step of flowing the liquid comprises flowing the liquid at a sufficient rate so that a volume of liquid overlying the opening being formed in the front wall during a first pulse of the laser beam is replaced with a fresh volume of liquid during the next pulse of the laser beam.

7. A method according to claim 3 wherein the step of forming comprises forming a hole through the front wall.

8. A method according to claim 5 including the step of providing a liquid which absorbs sufficient energy from the laser beam in the passage so that the laser beam is incapable of removing material from the back wall.

9. A method according to claim 8 wherein the step of providing the liquid includes providing a liquid and mixing the liquid with a laser beam energy absorbing additive.

10. A method according to claim 9 wherein the step of adding an additive comprises adding a laser beam energy absorbing dye to the liquid.

11. A method according to claim 10 wherein the step of providing a liquid comprises furnishing water as the liquid.

12. A method according to claim 5 wherein the step of flowing the liquid includes providing a liquid capable of scattering laser beam energy entering the passage from the opening in the front wall so that any laser beam energy reaching the back wall is incapable of removing material from the back wall.

13. A method according to claim 12 including the step of adding a scattering agent to the liquid in the passageway.

14. A method according to claim 13 wherein the step of adding a scattering agent comprises adding to the liquid particles of a material and size and in a quantity sufficient to scatter the laser beam energy.

15. A method according to claim 3 including the steps of providing a source of the liquid, and substantially continuously circulating the liquid from the source through the passage.

16. A method according to claim 15 including the step of withdrawing the liquid from the passage, conditioning the withdrawn liquid, and thereafter recirculating the conditioned liquid to the passage.

17. A method according to claim 16 wherein the step of conditioning comprises filtering the liquid.

18. A method according to claim 16 wherein the step of conditioning comprises cooling the liquid withdrawn from the passage.

19. A method according to claim 5 including the step of forming the workpiece from a material selected from the class consisting of metal, ceramic and plastic.

20. A method according to claim 19 wherein the opening comprises an orifice through the end wall having a transverse dimension in the range of between about 100-500μ.

21. A method according to claim 5 wherein the workpiece is a fuel injector for an internal combustion engine, and wherein the step of forming comprises the step of

forming at least one fuel injection orifice in the fuel injector.

22. A method of producing a fuel injector for an internal combustion engine, the fuel injector including a generally tubular part having a first, closed end and a second, open end and forming a passage therebetween, the injector defining a wall at the first end in which at least one fuel injection orifice is to be formed, the method comprising the steps of generating a laser beam having sufficient energy to form an orifice in the wall when directed against the wall; with the laser beam forming the orifice through the wall; filling the passageway with a liquid which attenuates the laser beam when it passes through the orifice into the passage sufficiently to disable the laser beam from damaging a surface of the injector facing the passage; and circulating the liquid through the open end of the injector into and out of the passage at a rate sufficient to continue the attenuation of the laser beam for as long as the laser beam passes through the orifice into the passageway.

23. A method according to claim 22 wherein the step of flowing the liquid comprises the steps of generating first and second fluid flows through the open end of the injector into and out of the passageway, respectively.

24. A method according to claim 23 wherein the step of generating the first and second fluid flows comprises extending an inlet conduit through the open end of the injector into the passageway so that the inlet conduit terminates proximate the end wall.

25. A method according to claim 24 wherein the step of extending the inlet conduit includes the step of providing an open-ended, hollow needle extending into the passageway.

26. A method according to claim 24 wherein the step of generating the second fluid flow comprises sealingly

connecting an outlet conduit to the open end of the injector and surrounding a portion of the inlet conduit extending out of the open end of the injector with the outlet conduit.

27. A method according to claim 22 including the step of forming a plurality of spaced-apart orifices in the end wall of the ejector, and moving the end wall relative to the laser beam for each successive orifice formed in the end wall.

28. Apparatus for forming an opening in a workpiece with a laser beam, the workpiece having a front wall, a back wall spaced from the front wall, and with the front wall defining a passage in the workpiece, the workpiece having at least one aperture communicating the passage with an exterior of the workpiece, the apparatus comprising a laser for generating a laser beam having sufficient energy to cut through the front wall; a holder for the workpiece which positions the workpiece so that the laser beam can be directed to a desired location for the opening in the front wall; a source of a liquid which, when placed in the passageway, prevents the laser beam from causing damage to the back wall when the laser beam penetrates through and forms an opening in the front wall into the passageway; and a flow circuit for the liquid fluidly coupling the source with the passage so that liquid from the source can be flowed into and withdrawn from the passage when the laser beam forms the opening.

29. Apparatus according to claim 28 wherein the workpiece has a single aperture communicating the passage with the exterior of the workpiece, and wherein the flow circuit comprises first and second conduits extending through the aperture of the workpiece into the passageway for flowing the liquid into and out of the passageway, and a seal operatively coupled with the conduits and the workpiece to prevent liquid from leaking from the aperture.

30. Apparatus according to claim 29 wherein the end wall is disposed at an end of the passage opposite from the open end, wherein one of the conduits is disposed inside the other one of the conduits, and wherein the seal is formed between the workpiece and the other one of the conduits.

31. Apparatus according to claim 30 wherein the one conduit extends into the passageway and has an open end proximate the end wall.

32. Apparatus according to claim 31 wherein the one conduit comprises an open-ended, hollow needle.

33. Apparatus according to claim 31 including a liquid flow control operatively coupled with the conduits and inducing a liquid flow into the passageway through the one conduit and a liquid flow out of the passageway through the other conduit.

34. Apparatus according to claim 31 including a fixture for moving the workpiece relative to the laser beam so that a plurality of openings can be made in the end wall.

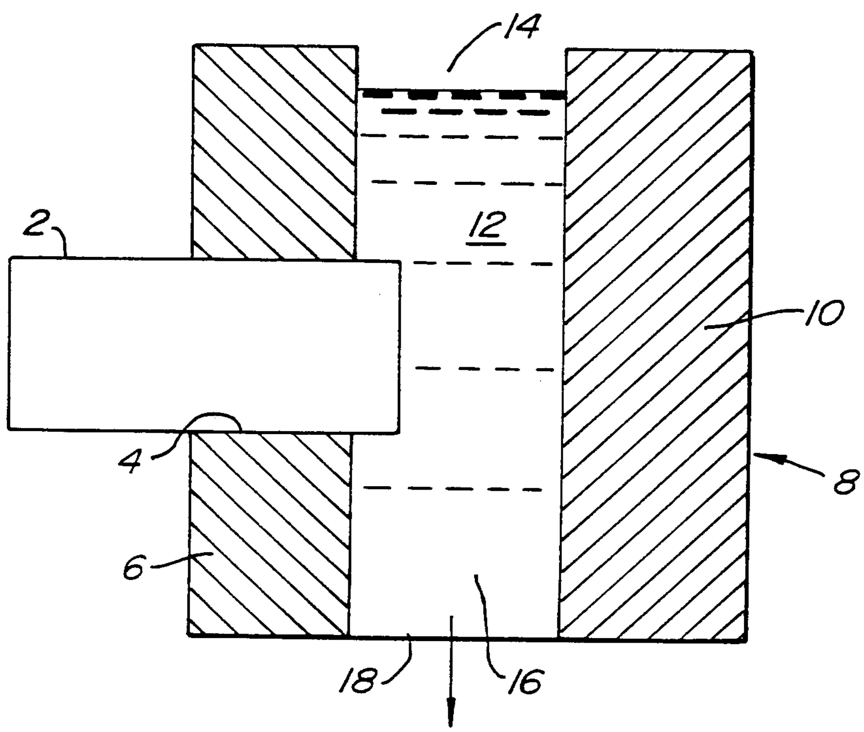


FIG. 1.

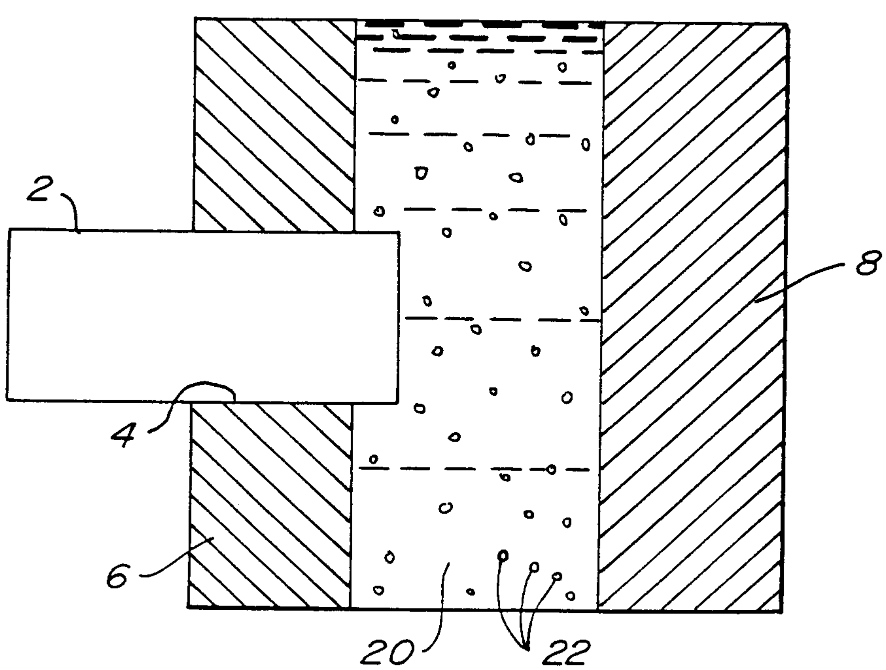


FIG. 2.

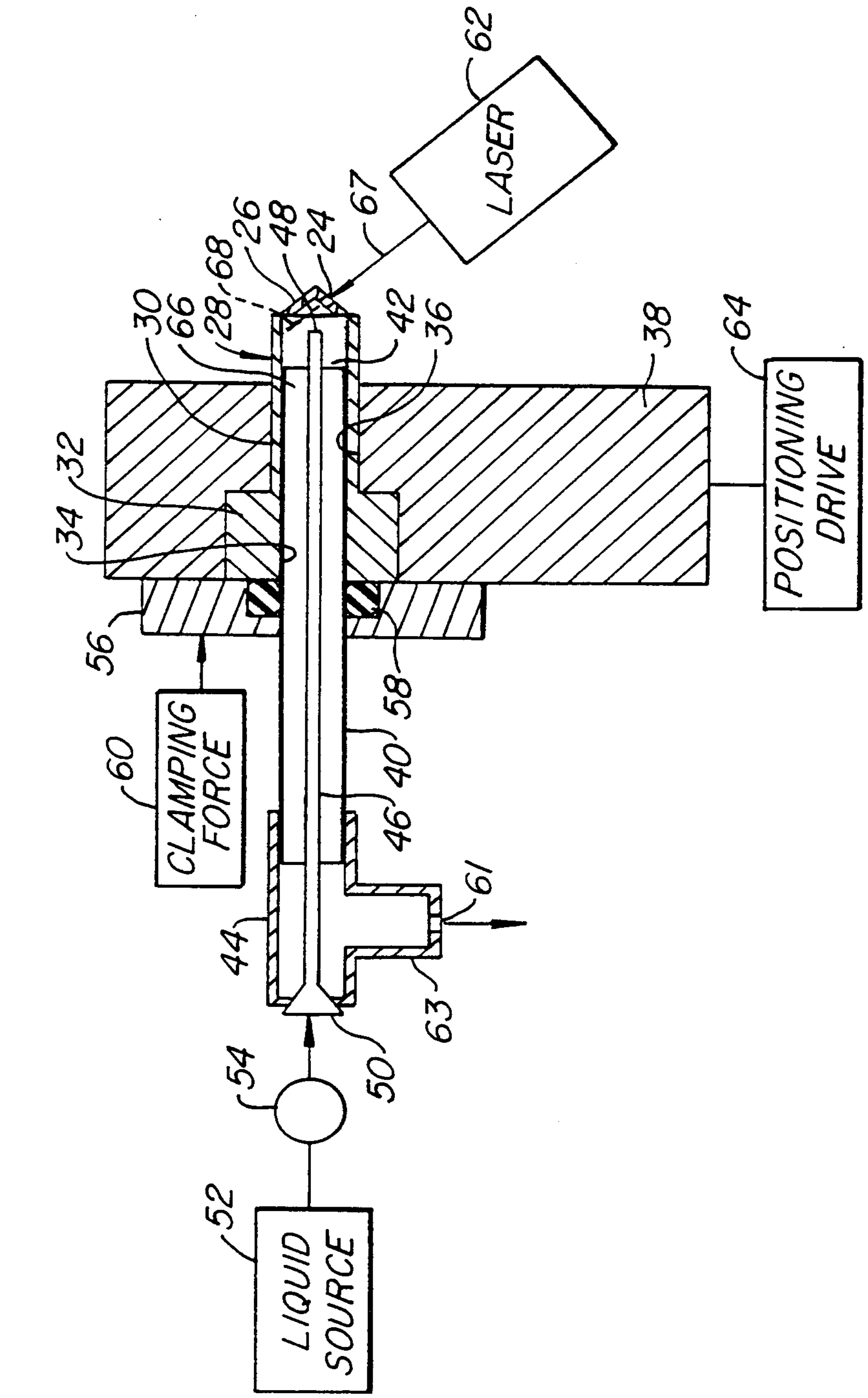

LASER
62
67
24
48
26
68
28
66
30
42
36
38
64
POSITIONING DRIVE
32
34
56
58
60
CLAMPING FORCE
40
46
44
61
63
50
54
52
LIQUID SOURCE

FIG. 3.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/11044

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : B23K 26*00
US CL : 219/121.7, 121.71
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 219/121.7, 121.71; 372/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 5,345,057 A (MULLER) 06 September 1994 (06/10/94), see entire document, especially column 3,lines 49-62.	1-9,15,19 ------------- 10-14,20-25,27,28
Y	US 3,975,692 A (MEGO JR. ET AL) 17 August 1976 (17/08/76), see entire document, especially column 1, line 53 to column 2, lines 21.	10,11
Y	US 4,873,414 A (MA ET AL) 10 October 1989 (10/10/89), see entire document, especially column 2, lines 2-40.	12,13,14
Y	US 4,288,679 A (LA ROCCA) 08 September 1981 (08/09/81), see entire document , especially column 2 , lines 37-40.	20-25,27, 28

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 JULY 1999	27 JUL 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer GEOFFREY S EVANS Telephone No. (703) 308-1653

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/11044

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,073,694 A (TESSIER ET AL) 17 December 1991 (17/12/1991), see entire document.	16-18, 26, 29-34